1 Supranuclear Pathways for Eye Movements

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INTRODUCTION

One is always confused about supranuclear pathways. We understand the pathways of the III, IV and VI cranial nerve nuclei. We would be able to trace it from the brain to the superior orbital fissure, but we fail to remember that these pathways we are discussing are the infranuclear pathways which extend from the cranial nerve nuclei to the ocular muscle. We need to also understand the anatomy of the supranuclear pathways.[1,2]

SUPRANUCLEAR AND INFRANUCLEAR PATHWAYS

Anatomical pathways, which extend from the cortical centers of the brain to the cranial nerve nuclei, are called the supranuclear pathways. From the cranial nerve nuclei to the ocular muscle exist the infranuclear pathways (Fig. 1.1).

In peripheral nerves, the nerve starts from the brain and reaches the anterior horn cell in the spinal cord. This is the upper motor neuron. From the anterior horn cell of the spinal cord, the nerve moves to the peripheral muscle. This is the lower motor neuron. If there is a lower motor neuron disease the limb is flaccid and if there is an upper motor neuron disease the limb is spastic.

The cranial nerve nuclei are like peripheral nerve nuclei. From the cortex of the brain the nerve extends to the cranial nerve nuclei and this is the upper motor neuron (UMN) pathway. From the cranial nerve nuclei the nerve extends to the ocular muscle and this is the lower motor neuron (LMN) pathway. In peripheral nerves if the anterior horn cell gets involved as in poliomyelitis, the patient has a LMN disease and so the limb is flaccid. The anterior horn cell is akin to the cranial nerve nuclei of cranial nerves. So, if the cranial nerve nuclei gets involved the lesion produced will be a LMN lesion.

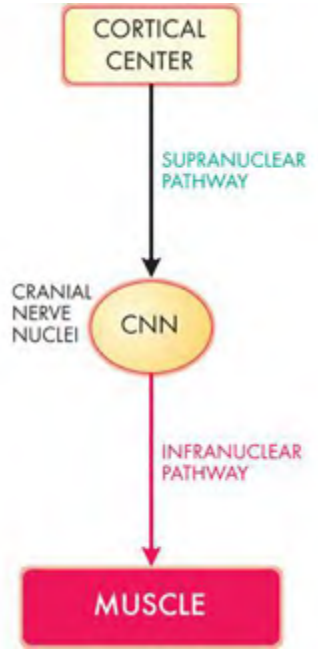

Fig. 1.1: Supranuclear pathway

SUPRANUCLEAR EYE MOVEMENT SYSTEMS

There are five supranuclear eye movement systems. They are:

1. Saccadic system
2. Pursuit system
3. Vergence system
4. Non-optic reflex system
5. Position maintenance system.

SACCADIC SYSTEM

The saccadic system is otherwise known as the fast eye movement system or rapid eye movement system. This is because the saccadic system controls the fast eye movements. These are command movements. For example if we say, look to the right, the eyes turn to the right. This occurs rapidly and is a rapid eye movement. The system, which controls this command pathway, is the saccadic system.

The saccadic system originates from the frontal lobe of the brain. The impulses then move to the mesencephalic system and so the anatomical pathway subserving the fast eye movements is the

frontomesencephalic pathway. When you watch someone watching a game of tennis or table tennis, you will notice the eyes move rapidly from one end of the court or table to the other. The eyes keep on darting from one end to the other. These are fast eye movements controlled by the frontomesencephalic pathway.

Horizontal Saccades

The saccades can in turn be horizontal or vertical. In horizontal saccades, the eyes move horizontally and in vertical saccades, the eyes move up and down. Let us now understand the pathway of the horizontal saccades (Fig. 1.2).

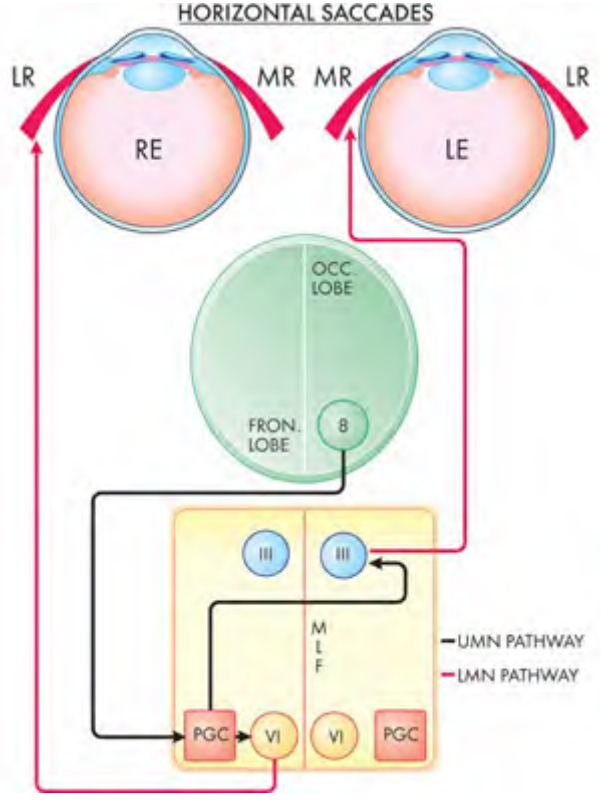

Fig. 1.2: Horizontal saccade pathway

LR- Lateral rectus; MR- Medial rectus; LE- Left eye; RE- Right eye; Occ.Lobe- Occipital Lobe; Fron.lobe- Frontal lobe; III- III Cranial nerve nucleus; VI- VI Cranial nerve nucleus; PGC- Pontine gaze center; MLF- Medial longitudinal fasciculus; UMN Pathway- Upper motor neuron pathway; LMN Pathway- Lower motor neuron pathway

If the eyes have to look to the right, then the command for this movement is given by the left frontal lobe in area 8 of the cortex. The nerves cross over to the opposite side and reach the right pontine gaze center. From here the nerves pass to the same side (in this case the right) VI nerve nuclei. From the right pontine gaze center nerves also pass to the opposite III nerve nuclei. In this case this will be the left III nerve nuclei. All the cranial nerve nuclei are connected with each other through the medial longitudinal fasciculus or medial longitudinal bundle. In other words from the right pontine gaze center, the nerves pass through the medial longitudinal bundle to the left III cranial nerve nuclei. Till here is the supranuclear pathway. This is why this is also called the frontomesencephalic pathway.

From the right VI nerve nucleus nerves then pass to the lateral rectus muscle of the right eye. From the left III nerve nucleus nerves pass to the left medial rectus muscle. These are the infranuclear pathways and both the eyes move to the right.

At this stage it is important to understand a bit more on the medial longitudinal bundle. As just explained, the nerves pass from the pontine gaze center to the VI and III nerve nuclei through the medial longitudinal bundle. If there is a lesion in the medial longitudinal bundle, these fibers are cut and there would not be a correlation between the III nerve and the VI nerve. This leads to the condition called internuclear ophthalmoplegia.

Vertical Saccades

The pathway for the vertical saccades is still doubtful. Vertical saccades depend on simultaneous bilateral activity within the frontal lobes in Area 8 (Fig. 1.3). This means that the horizontal saccades are unilaterally controlled whereas the vertical saccades are bilaterally controlled.

If one has to look up or down, impulses travel from both the frontal lobes in Area 8. The impulse travels via the basal ganglia to the pretectal area or the pretectal center for vertical gaze. This is the *vertical gaze center*. From the vertical gaze center impulses pass to the III nerve nuclei. Till here is the supranuclear pathway. Now, the infranuclear pathway starts and impulses go via the III cranial nerve to the vertical muscles and the patient looks up or looks down.

Because of the fact that vertical saccades require bilateral cortical activity, cerebral hemisphere lesions rarely produce deficits in the vertical saccades. Such deficits are seen only with massive hemispheric lesions producing bilateral damage to both frontomesencephalic

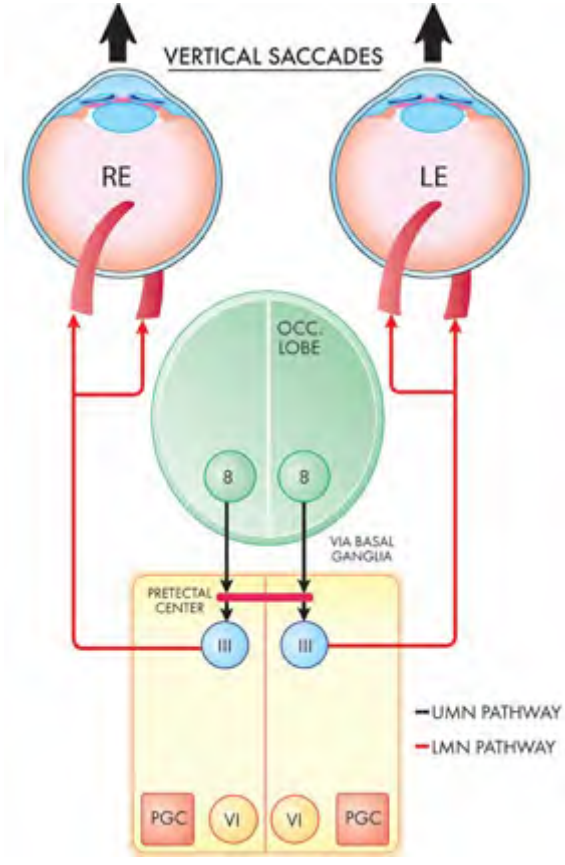

Fig. 1.3: Vertical saccade pathway

LE- Left eye; RE- Right eye; Occ.Lobe- Occipital Lobe; III- III Cranial nerve nucleus; VI- VI Cranial nerve nucleus; PGC- Pontine gaze center; MLF- Medial longitudinal fasciculus; UMN Pathway- Upper motor neuron pathway; LMN Pathway- Lower motor neuron pathway

pathways. Disturbances of vertical saccades are much more common with midbrain disorders.

Characteristic of the Saccade

The characteristic of the saccades is shown in Table 1.1 compared to the other supranuclear eye movements. From the onset of the stimulus, which is voluntary to the beginning of the recorded saccade, the latent period is about 200 to 250 msec. The velocity of the fast eye movement is 30 to 700 degrees/second.

PURSUIT SYSTEM

The smooth pursuit system is utilized when the eyes follow targets that move smoothly and relatively slowly. It maintains a fixed relationship between the movements of the eyes and the target. As smooth pursuit movements directly relate eye position to target position, they are also termed as *following or tracking movements*. As these movements are slow, they are called *slow eye movements*. Imagine a person walking and you are watching that person. When your eyes follow the movement of the person, they will be using the pursuit system. The pathway for the pursuit system starts from the occipital lobe and hence is known as the occipitomesencephalic pathway. There are different pathways for horizontal pursuits and for vertical pursuits.

Horizontal Pursuit System Pathway

If a target is moving to the right (Fig. 1.4), the first step is that the eyes have to visualize the object. So the pathway starts from the retina

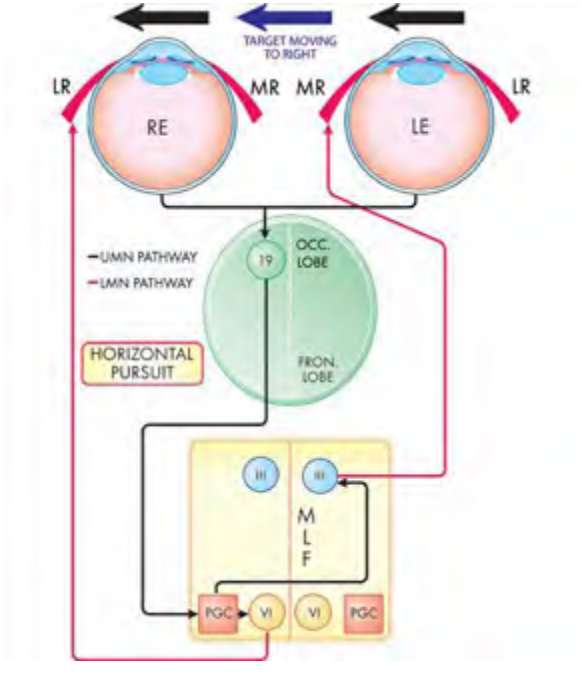

Fig. 1.4: Horizontal pursuit pathway (slow phase)

LR- Lateral rectus; MR- Medial rectus; LE- Left eye; RE- Right eye; Occ.Lobe- Occipital Lobe; Fron.lobe- Frontal lobe; III- III Cranial nerve nucleus; VI- VI Cranial nerve nucleus; PGC- Pontine gaze center; MLF- Medial longitudinal fasciculus; UMN Pathway- Upper motor neuron pathway; LMN Pathway- Lower motor neuron pathway

of both eyes. The impulses pass through the optic nerve, optic chiasma, and optic tract and reach the right occipital lobe in area 19. This area subserves the pursuit movements. It is important to note that the occipital areas mediate horizontal pursuit movements to the ipsilateral side. In other words, the right occipital lobe mediates horizontal pursuit movements to the right.

From the occipital lobe, impulses go to the same side pontine gaze center. In this case, impulses from the right occipital lobe go to the right Pontine gaze center. From here impulses go to the right VI nerve nucleus and the left III nerve nucleus. Till here is the supranuclear pathway. From the right VI nerve nucleus and the left III nerve nucleus impulses go via the infranuclear pathway to the lateral rectus and the medial rectus. The characteristics of the pursuits are shown in Table 1.1.

Corrective Saccade

When the target is moving away from the field of vision the eyes which were moving slowly to that side have to come back to their original position. A fast eye movement does this, in other words a saccade. This is the corrective saccade. If a stream of cars are going in front of our vision, then we keep on following one car and when it goes out of the field of vision our eyes would come and fixate back to the car in the center of our field of vision. This would be done by the corrective saccade.

As the impulses from the target moving to the right reaches the occipital lobe (Area 19) and the object is going out of the field of

Table 1.1: Characteristics of eye movements

Type	*Stimulus (msec)*	*Latency (Deg./Sec)*	*Velocity*	*Amplitude (Degrees)*	*Conjugacy*
1. Saccade	Volition, reflex	200	30-700	0.5-9.0	Conjugate
2. Pursuit	Target motion	125	< 50	0-90	Conjugate
3. Vergence	Accommodative, fusional	160	< 20	Age	Disjugate dependent
4. Vestibulo-ocular	Head movement	<100	< 400	0-90	Conjugate
5. Corrective saccade	Positions error	125	< 150	< 4	Conjugate
6. Micro-saccade	Fixation	-	3-12	1-25	Conjugate
7. Microdrift	Fixation	-	0-30 min/sec	<1	Disjugate

vision the occipital lobe sends impulses to the ipsilateral frontal lobe to perform the corrective saccade. In this case the right occipital lobe (Fig. 1.5) sends impulses to the right frontal lobe (Area 8). This means there has to be a communication between the occipital lobe and the frontal lobe. From the right occipital lobe impulses pass to the frontal lobe via the parietal lobe.

From the right frontal lobe, impulses then pass to the left pontine gaze center which in turn sends impulses to the left VI nerve nucleus and the right III nerve nucleus. This is the supranuclear pathway. Then, the infranuclear pathway takes over and impulses go to the respective lateral and medial recti and the eyes move to the left as a fast eye movement. This is the corrective saccade.

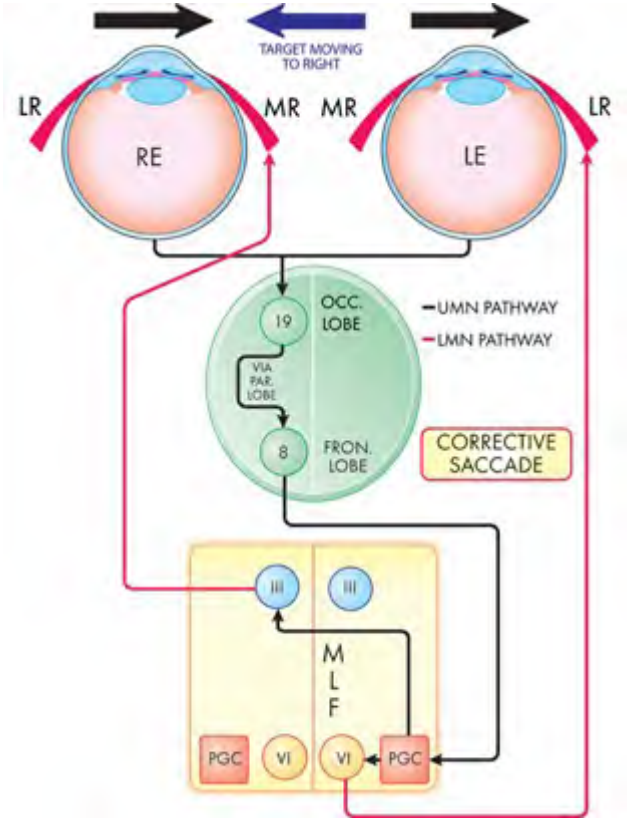

Fig. 1.5: Corrective saccade (Horizontal pursuit pathway for the fast phase)
LR- lateral rectus; MR- Medial rectus; LE- Left eye; RE- Right eye; Occ.Lobe- Occipital Lobe; Fron.lobe- Frontal lobe; III- III Cranial nerve nucleus; VI- VI Cranial nerve nucleus; PGC- Pontine gaze center; MLF- Medial longitudinal fasciculus; UMN Pathway- Upper motor neuron pathway; LMN Pathway- Lower motor neuron pathway

One can illustrate this with an optokinetic drum, which is a drum with black and white stripes. The drum is rotated and the eyes fixate on it. When the stripes go away from the field of vision, the corrective saccade occurs. This leads to a type of nystagmus known as optokinetic nystagmus.

Parietal Lobe Lesion

If the person has a parietal lobe lesion, then there is a problem (Fig. 1.6). When the corrective saccade has to work the impulse would not pass beyond the parietal lobe. Thus, this would lead to a deficit in the corrective saccade. So a deep parietal lobe lesion causes loss or decrease of the fast phase of the optokinetic nystagmus, when movement of the drum is towards the side of the lesion.

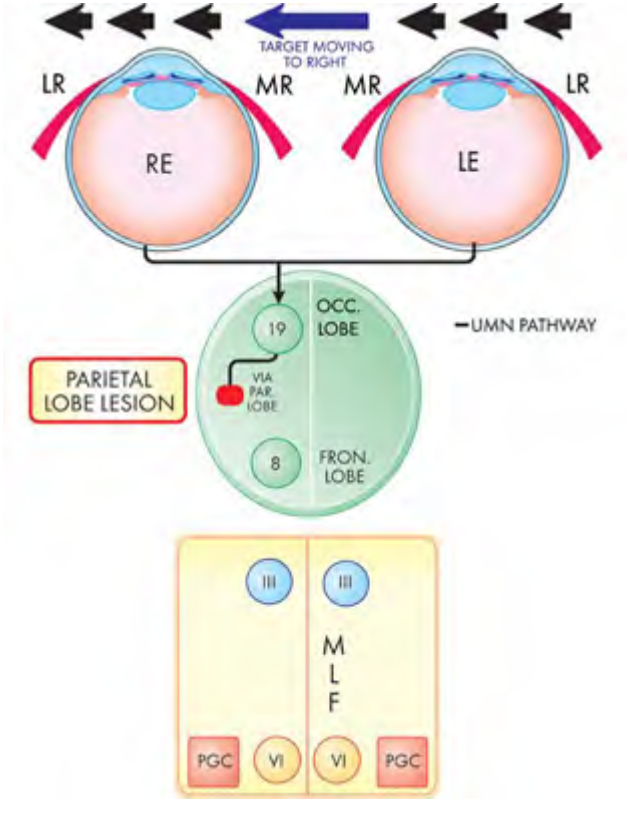

Fig. 1.6: Parietal lobe lesion

LR- Lateral rectus; MR- Medial rectus; LE- Left eye; RE- Right eye; Occ.Lobe- Occipital Lobe; Fron.lobe- Frontal lobe; III- III Cranial nerve nucleus; VI- VI Cranial nerve nucleus; PGC- Pontine gaze center; MLF- Medial longitudinal fasciculus; UMN Pathway- Upper motor neuron pathway

Vertical Pursuit System

Vertical pursuit movements are generated by simultaneous bilateral stimulation of area 19 of the occipital lobe (Fig. 1.7). The axons of the occipital lobe descend to the pretectal area. From the pretectal area impulses travel to the III nerve nuclei. Till here is the supranuclear or UMN pathway. Then from the III nerve nuclei, impulses pass to the vertical muscles via the infranuclear pathway. The pretectal area or pretectal center is the center for vertical gaze, analogous to the pontine gaze center, which is the center for horizontal gazes.

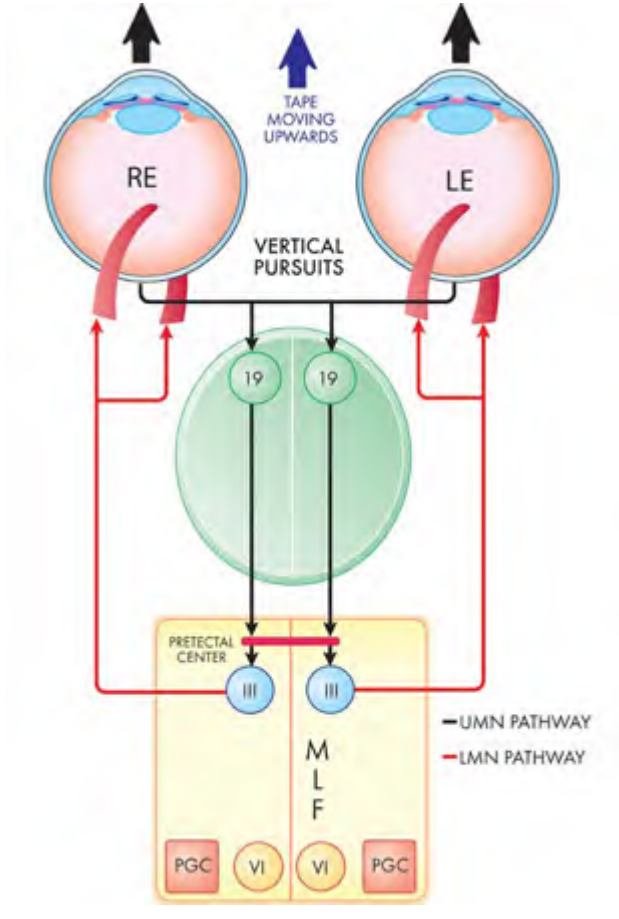

Fig. 1.7: Vertical pursuit pathway

LE- Left eye; RE- Right eye; III- III Cranial nerve nucleus; VI- VI Cranial nerve nucleus; PGC- Pontine gaze center; MLF- Medial longitudinal fasciculus; UMN Pathway- Upper motor neuron pathway; LMN Pathway- Lower motor neuron pathway

VERGENCE SYSTEM

The role of the vergence system is to keep the image of a target on appropriate points (corresponding elements) of the two retinas by controlling the visual axes of the eyes. Thus, vergence is utilized whenever a target falls on noncorresponding retinal elements. For example, if a target is moved towards the eyes, they must turn toward each other (converge) to keep the target on the fovea of each eye. Conversely, as the target is moved further away, the eyes must turn out (diverge) (Actually, divergence does not occur in our eyes.) Vergence is thus a disconjugate (nonparallel) movement of the eyes, in contrast to most other eye movements which are conjugate (parallel). There are two types of vergence. They can be voluntary—when we command our eyes to converge or reflex—when we bring an object or tape towards our nose and the eyes converge while fixating on the object. The characteristics of the vergence movements are shown in Table 1.1.

Voluntary Vergence

The center for voluntary vergence is situated in area 8 of the frontal lobe (Fig. 1.8). If one wants to converge then a command movement is sent from area 8. These are bilateral impulses and they go to the pretectal area via the basal ganglia. Here there is the convergence area. From the convergence area, impulses go bilaterally to the III and VI nerve nuclei. Till here is the supranuclear pathway. From the III nerve nuclei impulses go to the medial recti to converge. From the VI nerve nuclei inhibitory impulses go to the lateral recti so that the eyes can converge. Thus both the eyes converge.

Pursuit or Reflex Vergence

In this, the impulses originate from the retina of the two eyes (Fig. 1.9). If a pen is held in front of our eyes and moved towards the nose and if we keep looking at the pen, then the impulses from the two eyes will make the eyes converge by the pursuit vergence pathway. From the retina impulses will go via the optic nerve and tract to area 19 of the occipital lobe. This is a bilateral impulse. From here it goes to the pretectal area where it reaches the convergence area. From here impulses pass bilaterally to the III and VI nerve nuclei. This is the supranuclear pathway. Then positive impulses go to the medial recti and inhibitory impulses to the lateral recti and the eyes converge while looking at the object.

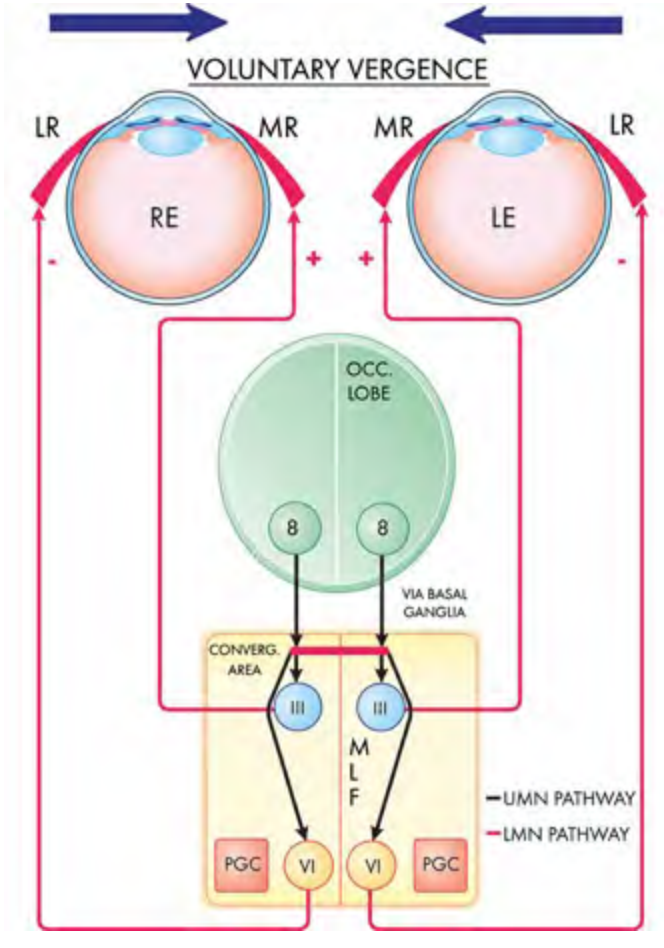

Fig. 1.8: Voluntary vergence pathway

LR- Lateral rectus; MR- Medial rectus; LE- Left eye; RE- Right eye; Occ.Lobe- Occipital Lobe; Fron.lobe- Frontal lobe; III- III Cranial nerve nucleus; VI- VI Cranial nerve nucleus; PGC- Pontine gaze center; MLF- Medial longitudinal fasciculus; UMN Pathway- Upper motor neuron pathway; LMN Pathway- Lower motor neuron pathway

NON-OPTIC REFLEX SYSTEM

The non-optic reflex system integrates eye movements and the body movements. There are basically three systems in this: (i) semicircular canals, (ii) neck receptors, and (iii) the cerebellum. The characteristics are shown in Table 1.1.

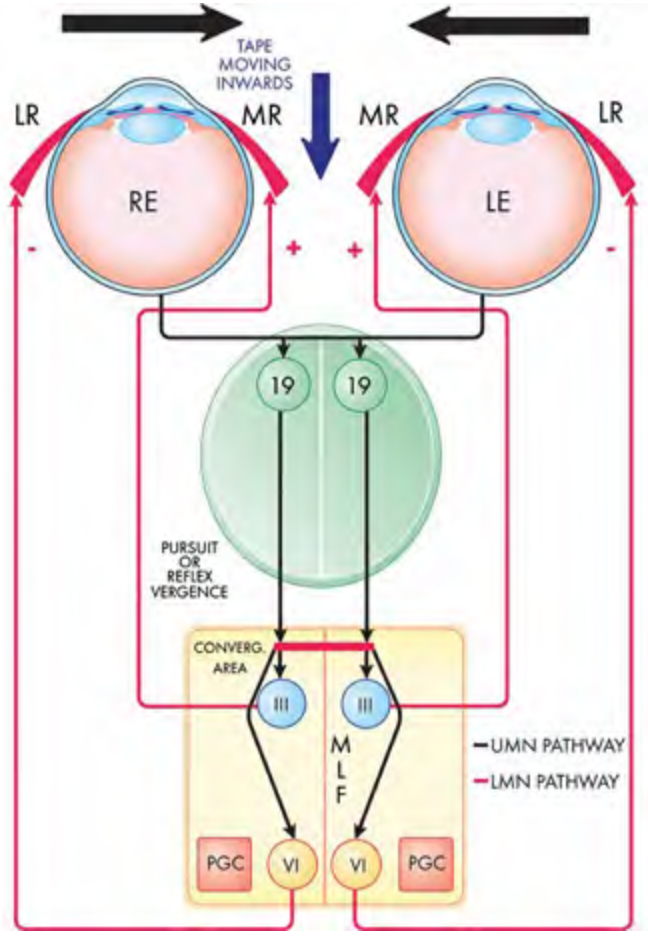

Fig. 1.9: Pursuit or reflex vergence pathway
LR- Lateral rectus; MR- Medial rectus; LE- Left eye; RE- Right eye; III- III Cranial nerve nucleus; VI- VI Cranial nerve nucleus; PGC- Pontine gaze center; MLF- Medial longitudinal fasciculus; UMN Pathway- Upper motor neuron pathway; LMN Pathway- Lower motor neuron pathway

Semicircular Canals

If a lateral semicircular canal is stimulated, the non-optic reflex system starts to work. If the head is rotated to the left (Fig. 1.10), the lateral semicircular canal is stimulated. If we tilt our head to the left, the eyes should generally keep looking straight ahead (the ultimate aim of the whole process). For the eyes to look straight ahead when we

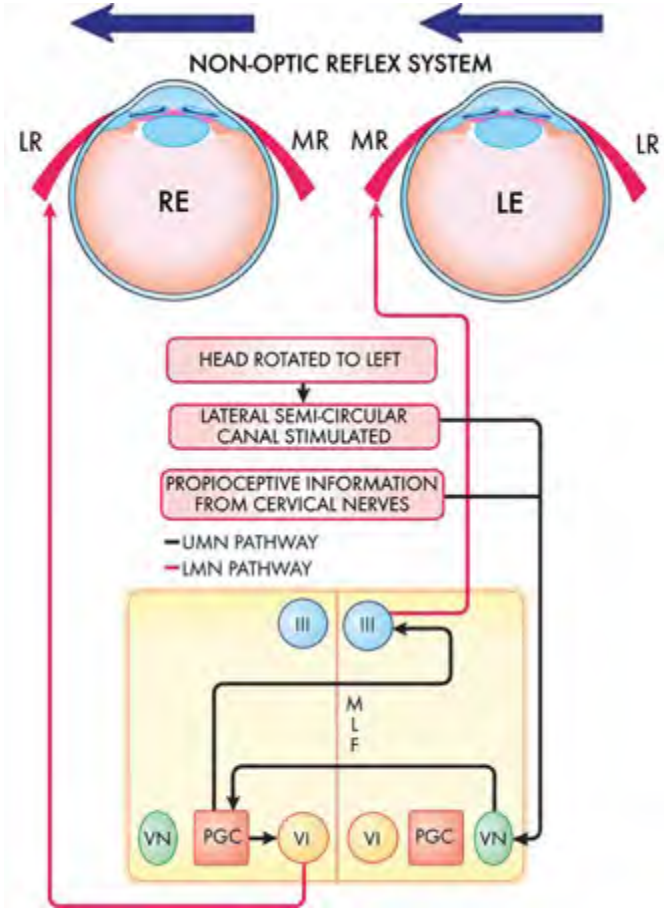

Fig. 1.10: Non-optic reflex system pathway

LR- Lateral rectus; MR- Medial rectus; LE- Left eye; RE- Right eye; III- III Cranial nerve nucleus; VI- VI Cranial nerve nucleus; PGC- Pontine gaze center; MLF- Medial longitudinal fasciculus; VN- Vestibular nucleus; UMN Pathway- Upper motor neuron pathway; LMN Pathway- Lower motor neuron pathway

have tilted our head to the left the eyes will move to the right. Try this on yourself by tilting your head to the left. You will note your eyes move to the right so that you keep on looking straight ahead.

When the semicircular canal is stimulated, impulse goes to the same side (in this case left side) vestibular nucleus. From the left vestibular nucleus, impulses go to the opposite side pontine gaze center which in turn send impulses to the right VI nerve nuclei and left III nerve nucleus. This is the supranuclear pathway. Then the infranuclear

pathway takes over to the right lateral rectus and left medial rectus and the eyes turn towards the right. This constitutes the vestibular influence on eye movements.

Neck Receptors

Contributory information also comes from the proprioceptive organs of the neck muscles via the spinovestibular tract.

Cerebellum

The role of the cerebellum is not very clear. There is a prominent flocculo-oculomotor tract, which is the only direct cerebellar connection with the eye nerve nuclei. This pathway connects with the opposite III nerve nuclei and the same side VI nerve nuclei (exactly opposite the semicircular canal connection, which connects with the same side III nerve and opposite side VI nerve nuclei). Thus, the eyes tend to move in the opposite direction. This pathway may help explain the reason why nystagmus in cerebellar disease is in the opposite direction to that occurring in vestibular disease.

POSITION MAINTENANCE SYSTEM

The function of the position maintenance system is to maintain an object of interest on the fovea or to maintain a specific gaze position. It is the most complex of eye movements and works efficiently only when the person is alert. It becomes seriously disturbed when the person's level of consciousness is depressed. The micromovement systems use the same substrates as its macrocounterparts, but the details of the pathways are not yet known.

The micro eye movements are known as microsaccades or flicks and micropursuits or drifts. The microsystem is continuously active in maintaining the target precisely on the fovea, presumable while other eye movement systems are active as well. Hence, it is the ultimate monitor of eye movements, coordinating all the other eye movement systems and determining the precise position of the eye with respect to the target as well as to the head and body. Stated simply, when an object moves more rapidly than the smooth pursuit system can follow it, a saccadic compensation is made to maintain the eye position relative to the moving target. The pursuit system has been overcome by the position maintenance system.

Take an example of your catching a ball. At that time when the ball is in the air, your saccadic and pursuit systems work so that your

eyes are on the ball. Sometimes, there would be an overshooting of either of the systems and at that time the micromovements of microsaccades and micropursuits take over so that you finally catch the ball.

SUMMARY

Thus, there are basically five supranuclear pathways, which control eye movements. It is important to know them if one wants to understand supranuclear lesions.

REFERENCES

1. Sunita Agarwal, Athiya Agarwal, et al. Textbook of Ophthalmology 4th vol; Jaypee, India 2003.
2. Amar Agarwal. Handbook of Ophthalmology; Slack USA 2005.